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Principal Mechanical Properties of Eastern Beech Wood (*Fagus orientalis* Lipsky) Naturally Grown in Andırın Northeastern Mediterranean Region of Turkey

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Abstract: The aim of this study was to determine some mechanical properties (compression, static bending, impact bending and shear strengths) of Eastern beech wood (*Fagus orientalis* Lipsky) and to compare with them other beech species. In the tests, randomly selected logs taken from the trunk 2-4 m height were obtained from trees naturally growing in Andırın (Northeastern Mediterranean region) and these logs were prepared and tested according to Turkish standards. The results showed that the mean compression strength was 606 kgcm⁻², static bending strength 1204 kgcm⁻², impact bending strength 0.85 kgmcm⁻² and shear strength 99 kgcm⁻². The relations of strengths with density were determined with regression analyses, and these were compared with other available values in the literature. As a result of this comparison, it was observed that Eastern beech trees growing in Andırın and other beeches have similar mechanical properties and density.

Key Words: Eastern beech (*Fagus orientalis* Lipsky), compression strength, static bending strength, impact bending strength, shear strength

Kuzey-doğu Akdeniz (Andırın) Yöresi'nde Doğal Olarak Yetişen Doğu Kayını (*Fagus orientalis* Lipsky)'nın Başlıca Mekanik Özelliklerinin Belirlenmesi

Özet: Bu araştırmada, doğu kayınının, basınç direnci, eğilme direnci, dinamik eğilme direnci ve makaslama dirençleri belirlenerek, bu değerlerin diğer kayın türleri ile karşılaştırılması amaçlanmıştır. Denemelerde test materyali olarak, doğu kayınının doğal olarak yetiştiği Andırın'dan (Kuzey-doğu Akdeniz yöresi) alınan deneme ağaçlarının 2-4 m'lik gövde kısımları kullanılmıştır. Denemelerde, doğu kayını odununda; basınç direnci 606 kgcm⁻², eğilme direnci 1204 kgcm⁻², dinamik eğilme (şok) direnci 0,85 kgmcm⁻² ve makaslama direnci 99 kgcm⁻² olarak elde edilmiştir. Direnç-özümlü ağırlık ilişkisi regresyon analizi ile araştırılmış ve araştırma bulguları, diğer yöre kayınları ile karşılaştırılmıştır. Bu kıyaslama ile Andırın yöresi ve diğer kayın odunlarının benzer mekanik özelliklere ve yoğunluğa sahip olduğu anlaşılmıştır.

Anahtar Sözcükler: Doğu kayını (*Fagus orientalis* Lipsky), basınç direnci, eğilme direnci, şok direnci, makaslama direnci

Introduction

The Eastern beech (*Fagus orientalis* Lipsky) is one of the most important commercial hardwood species in Turkish forestry. Although this species indigenously grows from Bulgaria to the Caucasus, there are abundant forest areas of Eastern beech along the Black Sea region in Turkey. It grows at high altitudes on mountains along the Black Sea coast, from Demirköy (Kırklareli) to Hopa (Artvin). It can also be seen in the Marmara region and some parts of Anatolia. For example, it has established local forests in Pos (Adana) and Andırın (Kahramanmaraş), which are situated in the Northeastern Mediterranean region of southern Turkey (Yaltrık, 1993).

The beech has high economic importance and it covers a total of 1 335 786 ha, equal to 6.43% of Turkey's forests (Konukçu, 2001). The Eastern beech, with 153 667 488 m³ wood value and 3 333 872 m³ annual allowable cut is the primary raw material for the Turkish forest product industry (Anonymous, 1989).

Beech wood is classified as a medium density hardwood and thus, it is heavy, hard, strong, high in resistance to shock, and is highly suitable for steam bending (Bozkurt and Erdin, 1997). Beech shrinks substantially and therefore requires careful drying. Mostly it is used for flooring, furniture, brushes, blocks, handles, veneer, woodenware, carpenters' work benches

and toys (Bozkurt and Erdin, 1997). When treated with preservatives, beech wood is suitable for railway ties (Yaltırık, 1993).

In this research, some mechanical properties of eastern beech, indigenously grown in Andirın (Northeastern Mediterranean region), were determined and these data were compared with other research results, available in the literature.

Materials and Methods

The selection of test areas and trees

The trial trees from which the wood samples were taken were obtained from Andirın Forests located in the Northeastern Mediterranean region of Turkey. First of all, by taking Turkish standards (TS) 4176/1984 into consideration, the average diameters of all trees at breast height was determined in two trial areas of the above-mentioned region. From each of those trial areas, two trees with a straight trunk and representing the average diameters of trees at breast height were cut. More detailed information can be found about these test areas and trees in Table 1.

Then, 1-m long end-matched log sections were prepared from the whole tree, cut from heights of between 2 and 4 m from the base as mentioned in TS 4176/1984 (Figure 1a.). CuSO_4 solution (10%) was sprayed onto cross sections of 1-m long green logs in order to prevent staining and they were left for pre-drying for 3 months.

Later, from these selected sections (Figure 1b.), test specimens were prepared for the determination of compression strength parallel to the grain, static bending strength, impact bending strength and shear strength parallel to the grain. The determinations of physical properties (density and annual ring orientation etc.) was described in a previous paper (Bektaş and Güler, 1999).

Compression strength parallel to the grain

The compression strength was measured according to TS 2595/1977 with the exception that the dimensions of sound specimens were 4 (R) x 4 (T) x 6 (L) cm. The test was performed on a one ton universal testing machine (Losenhausen Model) and crosshead motion or rate of loading was 0.6 mm/min. Specimens were conditioned at a temperature of 20°C and $65 \pm 5\%$ relative humidity to the moisture content (MC) of about 12%. Specimen dimensions were measured to the nearest 0.001 mm. The test was performed on 80 specimens. The compression strength parallel to the grain was calculated by the following equation (Bozkurt and Göker, 1986):

$$\sigma_{\text{cpl}} = \frac{P_{\text{max}}}{F} \text{ (kgcm}^{-2}\text{)} \quad (1)$$

where σ_{cpl} is the compression strength (kgcm^{-2}), P_{max} is the maximum load at the break point (kg) and F is area of cross section of a specimen on which force was applied (cm^2).

The effects of the moisture content in the broken specimens were determined according to TS 2471/1976.

| | Test area I | | Test area II | |
|---------------|-----------------------|-------------------------|-------------------------|-----|
| Test areas | Latitude (N°) | 37° 46' 27"-37° 36' 51" | 37° 46' 27"-37° 36' 51" | |
| | Longitude (E°) | 36° 19' 13"-36° 36' 24" | 36° 19' 13"-36° 36' 24" | |
| | Elevation (m) | 1740 | 1740 | |
| | Exposure | northeast | northeast | |
| | Slope (%) | 25 | 20 | |
| | Rainfall (mm/year) | 722.8 | 722.8 | |
| | Summer rainfall (mm) | 3 | 3 | |
| | Max. temperature (°C) | 42.6 | 42.6 | |
| | Min. temperature (°C) | -9 | -9 | |
| | Test trees | No | 1 | 2 |
| Age | | 106 | 98 | 114 |
| Diameter (cm) | | 37 | 30 | 30 |
| Length (m) | | 17 | 18 | 21 |

Table 1. The characteristics of the test areas and trees.

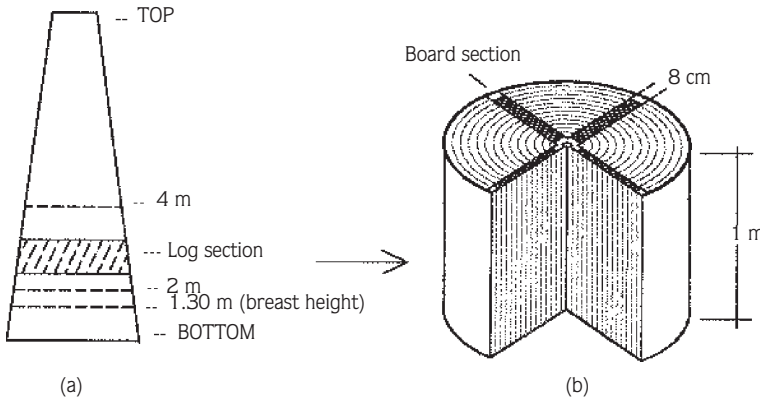


Figure 1. a) Location of the experimental log section in tree; b) Location of the experimental board section on the cross-section of the log.

In this case, the compression strength of the specimen in which moisture content deviated from 12% was adjusted by the following equation:

$$\sigma_{cpl12} = \sigma_{cpl} [1+0.06 (M-12)] \text{ (kgcm}^{-2}\text{)} \quad (2)$$

where σ_{cpl12} is the compression strength at the moisture content of 12% (kgcm⁻²), σ_{cpl} is the compression strength at the actual moisture content level (kgcm⁻²), and M is the moisture content.

Determination of static quality value

Hardwood trees are sometimes classified based upon a relationship between compression strength parallel to the grain and the air-dry density of wood species, which is called "static quality value" and is formulated by the following equation (As, 1992):

$$I_s = \frac{\sigma_{cpl}}{100 \cdot d_{12}} \quad (3)$$

where, I_s is the static quality value, σ_{cpl} is the compression strength parallel to the grain (kgcm⁻²) and d_{12} is the air-dry density (gcm⁻³).

The static quality value is thus determined for Eastern beech grown in Andırın in this study.

Static bending strength

The test of bending strength perpendicular to the grain, i.e., modulus of rupture (MOR= σ_{sbs}), was performed according to TS 2474/1976 with the exception that specimens had a dimensions of 2 (R) x 2 (T) x 36 (L) cm. Specimens were conditioned at a

temperature of 20°C and 65±5% relative humidity to the moisture content of about 12% as in the other tests. The bending test was done on the same universal testing machine as used for the compression test. The load was applied to the radial surface of specimens and the loading speed was one mm/min and for this test; 100 samples were used. The MOR of the specimens was calculated by the following equation (Örs, 1986):

$$\sigma_{sbs} = \frac{3 \cdot P_{max} \cdot L}{2 \cdot b \cdot h^2} \text{ (kgcm}^{-2}\text{)} \quad (4)$$

where σ_{sbs} is MOR (kgcm⁻²), P_{max} is the maximum load at break point (kg), L is the length of span (30 cm), b is the width of specimen (cm), and h is the thickness of the specimen (tangential to annual ring) (cm). The moisture contents of the broken specimens were determined according to TS 2471/1976. The bending strength of the specimen whose moisture content deviated from 12% was adjusted by the following equation (Bozkurt and Göker, 1996):

$$\sigma_{sbs12} = \sigma_{sbs} [1+0.04 (M-12)] \text{ (kgcm}^{-2}\text{)} \quad (5)$$

where σ_{sbs12} is the bending strength at a moisture content of 12% (kgcm⁻²), σ_{sbs} is the bending strength at actual moisture content (kgcm⁻²) and M is the moisture content.

Impact bending strength

Impact bending strength was determined according to TS 2477/1976 and the specimen size was 2 (R) x 2 (T) x 30 (L) cm. Specimens were conditioned at a temperature of 20°C and 65±5% relative humidity for 3 months to the equilibrium moisture content of about 12%. The

impact bending strength of the specimens was tested on an impact tester (Model HPSW 10) and the speed of the hammer was 86 m/sec. The impact bending strength was calculated by the following equation (Berkel, 1970):

$$\sigma_{w12} = \frac{a}{F} \text{ (kgmcm}^{-2}\text{)} \quad (6)$$

where σ_{w12} is the impact bending strength (kgmcm⁻²), a is the energy absorbed by the specimen (kgm) and F is the cross-sectional area of the specimen (cm²).

Determination of dynamic quality value

Hardwood trees are classified based upon a relationship between impact bending strength and oven-dry density of wood species, which is called “dynamic quality value” and is formulated by the following equation (Berkel, 1970):

$$I_d = \frac{\sigma_{w12}}{d_0^2} \quad (7)$$

where I_d is dynamic quality value, a is impact bending strength (kgmcm⁻²) and d_0 oven-dry density (gcm⁻³).

Shear strength parallel to the grain

Small, straight-grained, clear-cut samples were prepared and conditioned prior to the test as in the other tests. The test was done according to TS 3459/1980 on a ton universal testing machine (Losenhausen Model) and samples had radial surfaces. Shear strength was calculated from the following equation (Bektaş, 1997):

$$\sigma_{ss} = \frac{P_{max}}{2.b.L} \text{ (kgcm}^{-2}\text{)} \quad (8)$$

where σ_{ss} is shear strength (kgcm⁻²), P_{max} is the maximum load at break point (kg), b is the thickness of specimens (cm) and L is the length of samples (cm).

Some modifications were made due to MC deviation from 12% MC for some test samples. These modifications were made according to the information in the literature that 1% MC reduction can cause 3% strength increment (As, 1992). Therefore, the following equation was used for this purpose:

$$\sigma_{ss12} = \sigma_{ss} [1+0.03 (M-12)] \text{ (kgcm}^{-2}\text{)} \quad (9)$$

where σ_{ss12} is shear strength at 12% MC (kgcm⁻²), σ_{ss} is shear strength at actual MC (kgcm⁻²) and M is moisture content (%).

Results and Discussion

Statistical analyses were carried out for each test, namely, compression, static bending, impact bending and shear strengths, and the values are presented in Table 2. In this section, these results (Table 2) and other available research results (Table 3) will be compared.

According to Table 3, Eastern beech trees grown in Andirın have the highest static bending strength among all of the beech species in that table. However, compression strength is lower than that for Sinop and Tokat beeches, but higher than that for Black Sea and Iran beeches. Impact bending strength is lower than that for Black Sea and Sinop Eastern beeches and European beeches, but higher than that for Iran and Tokat Eastern beeches. Shear strength is lower than for Black Sea beeches. In addition, Andirın beeches have higher air-dry density and annual growth rings than Sinop and Iran beeches, but lower than those of the other species presented in Table 3. In general, there is a small correlation between age, annual ring wide and density in diffuse porous wood (Panshin and Dezeeuw, 1980); on

| Beech wood | σ_{cp12}^a | σ_{sb12}^b | σ_{w12}^c | σ_{ss12}^d |
|--|-------------------|-------------------|------------------|-------------------|
| Number of samples (N) | 80 | 100 | 93 | 75 |
| Average (X) | 606 | 1204 | 0.85 | 99 |
| Standard deviation (S) | 43.29 | 457.81 | 0.24 | 21.17 |
| Coefficient of variation (S ²) | 7.15 | 35.09 | 28.07 | 21.45 |
| Minimum value (X _{min}) | 500 | 564 | 0.43 | 55 |
| Maximum value (X _{max}) | 711 | 2871 | 1.74 | 153 |

Table 2. Descriptive statistics of the results of Eastern beech wood naturally grown in Andirın.

^aCompression strength parallel to grain (kgcm⁻²), ^bStatic bending strength (kgcm⁻²), ^cImpact strength (Kgmcm⁻²), ^dShear strength (kgcm⁻²).

Table 3. Comparison of some mechanical properties of Andırın beech with other beech species.

| Tree species | Arw ^a | D ₁₂ ^b | σ_{cp12} ^c | σ_{sbs12} ^d | σ_{w12} ^e | σ_{ss12} ^f | References |
|----------------|------------------|------------------------------|------------------------------|-------------------------------|-----------------------------|------------------------------|--------------------------------|
| FO (Andırın) | 1.51 | 0.663 | 606 | 1204 | 0.85 | 98.7 | (Bektaş and Güler, 1999) |
| FO (Black Sea) | 1.64 | 0.669 | 572 | 1123 | 0.95 | 99.7 | (Malkoçoğlu, 1994) |
| FO (Sinop) | - | 0.660 | 644 | 870 | 0.92 | - | (Berkel, 1941) |
| FO (Iran) | 1.46 | 0.658 | 564 | - | 0.70 | - | (Pojouh, 1974) |
| FO (Tokat) | - | 0.663 | 763 | 1052 | 0.45 | - | (Gürsu, 1960) |
| FS (European) | 1.64 | - | 648 | - | 0.94 | - | (Horvat, 1969) |
| FS (European) | 2.22 | 0.698 | 527 | 1102 | 0.98 | - | (Cividini, 1969) |
| FS (European) | - | 0.716 | 521 | 1105 | 0.85 | 98.3 | (Stoyanoff and Entcheff, 1949) |

FO: *Fagus orientalis*,^aAnnual ring width (mm),^bAir-dry density (gcm⁻³),^cCompression strength parallel to grain (kgcm⁻²),FS: *Fagus silvatica*^dStatic bending strength (kgcm⁻²),^eImpact strength (kgmcm⁻²),^fShear strength (kgcm⁻²).

the other hand, higher altitude can cause lower density. Beech trees generally grow at 500-1800 m in Turkey, and the Eastern beech grows at high altitude (1800 m) in Andırın and so it has a low density. Furthermore, the variations in the mechanical properties in the same species are due to different factors, such as growth conditions and ecological factors. In particular, exposure, altitude, soil and climate conditions can affect the mechanical properties of wood. Sample size and properties (e.g. ring orientation), and the test procedure can also affect the test results. For all these reasons, some properties of Andırın beech wood showed properties slightly different to those of other beech species.

Medium density hardwoods, such as beech, can be classified as low, fair and good quality according to their static quality value (I_s). In this case, $I_s < 7$ is low quality, $7 < I_s < 8.5$ is fair quality and $8.5 < I_s$ is good quality. According to this classification, the Eastern beeches that grow in Andırın are good quality along with the other Eastern beeches in Table 4, but European beeches are fair quality.

Furthermore, medium density hardwoods, such as beech, can be classified as low, fair and good quality according to the value of dynamic quality (I_d) also. $I_d < 1$ is low quality, $1 < I_d < 2$ is fair quality and $2 < I_d$ is good quality wood. According to this classification, the Eastern beeches that grow in Andırın are fair quality along with Iran and Tokat, whereas Sinop and Black Sea beeches are good quality (Table 4).

For an ordinary wood species, the p value, the ratio between static bending strength and compression strength, is considered to be 1.75 (Bektaş, 1997). In the present study, it was found that the calculated p value for Andırın is higher than this 1.75, including Black Sea and European beeches. However, the p values of other Eastern beeches are lower than the accepted p value (Table 4). Therefore, Eastern beech trees in Andırın have good quality wood as indicated by the higher p value.

Another criterion for the evaluation of the wood's properties is the value of q, a ratio between compression strength and density (Bozkurt and Göker, 1996). Each wood species has a specific q value but there is no classification; nevertheless, this value is used to compare the wood with other non-wood materials and it is used in some calculations for industrial applications. According to this criterion, Andırın beech has a higher value than the other beeches in Table 4, except Sinop and Tokat beeches.

The effect of density on mechanical properties, bending, compression and shear strengths was tested statistically by linear regression analyses and the linear equations derived from all the linear regression analyses illustrated in Figures 2-4 are listed in Table 5. For these analyses, the relationship between compression strength and air-dry density is presented in Figure 2, the relationship between bending strength and oven-dry density in Figure 3, and the relationship between impact bending strength and oven-dry density in Figure 4.

Table 4. Some values of the beech wood species.

| Tree species | I_s^a | I_d^b | D_0^c | P^d | q^e | References |
|----------------|---------|---------|---------|-------|-------|--------------------------------|
| FO (Andirın) | 9.14 | 1.94 | 0.631 | 1.98 | 961 | (Bektaş and Güler, 1999) |
| FO (Black sea) | 8.55 | 2.12 | 0.645 | 1.96 | 887 | (Malkoçoğlu, 1994) |
| FO (Sinop) | 9.75 | 2.11 | 0.633 | 1.35 | 1017 | (Berkel, 1941) |
| FO (Tokat) | 11.5 | 1.02 | 0.589 | 1.38 | 1295 | (Gürsu, 1960) |
| FO (Iran) | 8.57 | 1.62 | 0.632 | - | 892 | (Pojouh, 1974) |
| FS (European) | 7.55 | 2.01 | 0.669 | 2.09 | 788 | (Cividini, 1969) |
| FS (European) | 7.28 | 1.47 | 0.671 | 2.12 | 776 | (Stoyanoff and Entcheff, 1949) |

FO: *Fagus orientalis*,

^aThe value of static quality,

^bThe value of dynamic quality,

^cOven-dry density,

FS: *Fagus silvatika*

^dStatic bending strength/Compression strength parallel to grain (according to Table 3),

^eCompression strength parallel to grain /Oven-dry density (according to Table 3)

| properties | equations | r^d | r^{2e} | r and r^2 |
|-------------------------|---------------------|-------|----------|-----------------------------|
| $\sigma_{cp12}^a - D12$ | $Y = 202 + 637x$ | 0.71 | 0.51 | $r > 0.70$ and $r^2 > 0.50$ |
| $\sigma_{sbs12}^b - D0$ | $Y = -252 + 2737x$ | 0.75 | 0.56 | $r > 0.70$ and $r^2 > 0.50$ |
| $\sigma_{w12}^c - D0$ | $Y = -1.02 + 3.01x$ | 0.73 | 0.53 | $r > 0.70$ and $r^2 > 0.50$ |

Table 5. Equations derived from regression analyses.

^aCompression strength parallel to grain (kgcm^{-2}) and air-dry density (gcm^{-3}),

^bStatic bending strength (kgcm^{-2}) and oven-dry density (gcm^{-3}),

^cImpact strength (Kgmcm^{-2}) and oven-dry density (gcm^{-3}),

^dCoefficient of correlation,

^eCoefficient of determination.

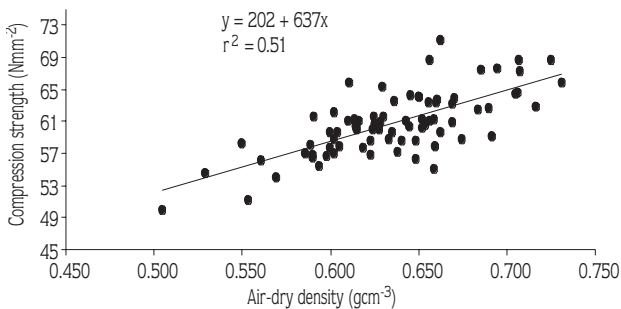


Figure 2. The relationship between compression strength and air-dry density.

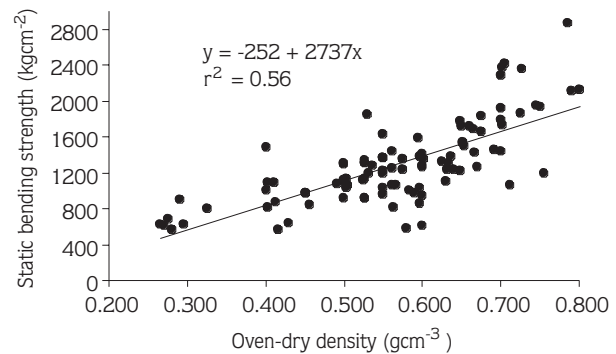


Figure 3. The relationship between static bending strength and oven-dry density.

Figures 2-4 show that there are good relationships between compression strength and air-dry density, static bending strength and oven-dry density, and impact bending strength and oven-dry density; the coefficients of

correlation (r) are 0.71, 0.75, and 0.73, and the coefficient of determination (r^2) are 0.51, 0.56, and 0.53, for these data, respectively. These values are consistent with a statistically significant correlation.

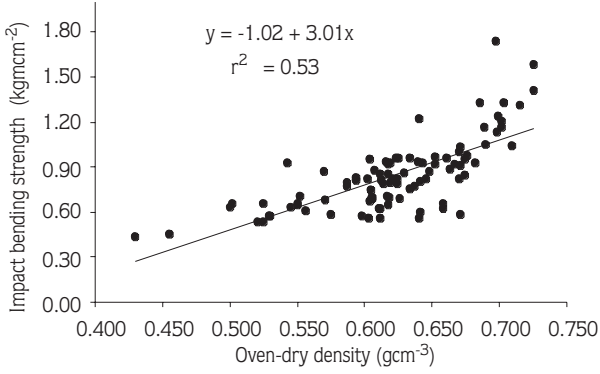


Figure 4. The relationship between impact bending strength and oven - dry density.

Conclusions

In this study, the principal mechanical properties (compression, static bending, impact bending and shear strengths) of Eastern beech trees in Andırın were determined and these results were compared with those of other research beech wood in different regions. The test results proved that the Eastern beech trees in Andırın have medium-tough, elastic and good quality wood. There are some differences other beeches and Eastern beeches in Andırın. These differences may be explained by some regional conditions, that affects the growth

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characteristics and properties of the wood. In this case, the lower density of the Eastern beech trees in Andırın has led to some lower mechanical properties, due to the high altitude.

This research showed that there is a linear relationship between selected mechanical properties and the density of Eastern beech trees in Andırın; nonetheless, those statistically significant data were not very strong due to the number of trees used in this study. For future research, the number of test trees should be increased and the region should be wider and different locations should be selected.

Eastern beech trees in Andırın with narrow annual growth rings (1.51 mm), with respect to strength and density (0.663 gcm⁻³) can be used in many different usage areas where other beech species are today. In light of this research, Eastern beech wood from Andırın is a good material for the Turkish forest products industry; therefore, plantation of this species should be considered for the Eastern Mediterranean region.

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